



# Parametric Optimization of GMAW of Dissimilar Steels: Duplex Stainless Steel 2205 and Stainless Steel 316L

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**Abstract**—The objective of the thesis is to find out the optimum process parameters for GMAW between duplex stainless steel 2205 and stainless steel 316L. The welding parameters selected for the experiments are current, voltage, and gas flow rate. The optimization is carried out by choosing three input parameters at three levels. Multi objective optimization technique grey relational optimization theory is used for maximizing the tensile strength, impact strength and weld metal hardness. ANOVA is performed to investigate the more influencing parameters on the multiple performance characteristics. It also helps to calculate percentage contribution of each parameter. Finally analyzed the tensile strength, hardness and impact strength and also the microstructure corresponding to optimum value.

**Index Terms**—Duplex Stainless Steel 2205, GMAW, Grey Relational Theory, Stainless Steel 316L.

## I. INTRODUCTION

Design engineers are increasingly faced with the need to join dissimilar materials because they are seeking creative new structures or parts with tailor-engineered properties. Structures may need toughness or wear resistance in one area combined with high strength in another location. Joining dissimilar materials is often more difficult than joining the same material or alloys with minor differences in composition; however, many dissimilar materials can be joined successfully with the appropriate joining process and specialized procedures. A successful weld between dissimilar metals is one that is as strong as the weaker of the two metals being joined, i.e., possessing sufficient tensile strength and ductility so that the joint will not fail in the weld. Such joints can be accomplished in a variety of different metals and by a number of the welding processes. Joining dissimilar alloys could significantly reduce the cost and weight of production without compromising the safety and structural requirements. Presently, the methods of joining dissimilar metals include GMAW, GTAW, SAW, fusion welding, pressure welding, explosion welding, friction welding, diffusion welding, brazing, and soldering. GMAW finds widespread industrial use as a continuous welding process

for joining materials. This process allows welding of several materials that are extremely difficult to weld continuously. Welding process parameters play a significant role in making good quality joints. To produce a good quality joint it is important to set up proper welding process parameters. This can be done by employing optimization techniques.

The duplex stainless steels have been developed to provide a combination of strength and resistance to pitting and stress corrosion cracking in comparison with the 300-series austenitic stainless steels [1-3]. These unique properties of the duplex stainless steels have resulted in their use in a variety of industrial applications, including, nuclear power plants, chemical process plant piping, oil and gas transmission lines, and structures for use in marine environments [4,5].

The 2205 is a duplex (austenitic-ferritic) stainless steel that combines many of the best properties of austenitic and ferritic stainless steels. High chromium and molybdenum contents provide high resistance to pitting and crevice corrosion. The duplex structure is highly resistant to chloride stress corrosion cracking. DSS 2205 has superior strength and toughness and possesses good weld ability [6,3]. 2205 duplex stainless steel (DSS) combines ferritic steel and austenitic steel features [7,3]. The presence of austenite can restrain the appearance of coarse grains and improve the toughness of ferritic steel [8,3], while the presence of ferrite can improve the yield strength and reduce the occurrence of stress corrosion cracking or hot cracking of the austenitic steel [9-11].

Austenitic-ferrite balance with 30–55% ferrite (typically about 45% ferrite) should be maintained and controlled in DSS 2205. Significant deviations in the ratio of the austenite-ferrite from this range can negatively influence the mechanical properties and corrosion resistance of the welded joint. Extremely low ferrite content (<25%) can lead to a reduction in the strength and a risk of stress corrosion cracking. Extremely high ferrite content (>75%) can result in reduced corrosion resistance and impact toughness. [3,9]

Platt et al. [14] were conducting an electrochemical and immersion (crevice) corrosion tests on both 2205 duplex stainless steel and 316L stainless steel in 37 degrees C, 0.9 wt% sodium chloride solution. Electrochemical testing indicates that 2205 has a longer passivation range than 316L. The corrosion rate of 2205 was 0.416 MPY (milli-inch per year), whereas 316L exhibited 0.647 MPY. When 2205 was coupled to 316L with equal surface area ratio, the corrosion rate of 2205 reduced to 0.260 MPY, indicating that 316L stainless steel behaved like a sacrificial anode.[13]

Duplex steel can be welded to austenitic stainless steels. When welding to austenitic grades, the austenitic filler metals with low carbon and molybdenum content intermediate between the two steels are typically used. AWS ER309LMO is frequently used for these joints. If nickel base filler metals are used, they should be free of niobium. Because austenitic stainless steels have lower strength than duplex steels, welded joints made with austenitic filler metals will not be as strong as the duplex base metal [15].

Taguchi Technique is applied to plan the experiments [16]. Orthogonal arrays were introduced in the 1940s and have been widely used in designing experiments. It is used to reduce the number of experiments needed to be performed than the full factorial experiment. In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development so that high quality products can be produced quickly and at low cost. Taguchi's parameter design is an important tool for robust design. Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments [17].

Grey Relational theory has been widely used in engineering analysis, and it reveals the potential to solve the setting of optimal process parameters associated with a process with multiple output parameters. Lohithaksha M Maiyar et al. [17] have discussed the multi objective optimization of end milling operation. There are 3 main steps in Grey Relational Analysis [18]. They are Data Pre-Processing, Grey Relational Coefficient calculation and Grey Relational Grade determination.

To produce a good quality joint, it is important to set up proper welding process parameters. This can be done by employing optimization techniques. The objective of the thesis is to find out the optimum process parameters for GMAW process by grey relational analysis. Finally analyze optimized result of GMAW with GTAW, in terms of mechanical properties, composition, and corrosion rate.

## II. EXPERIMENTAL PROCEDURE

### A. Material and Processes

The base metals employed are duplex stainless steel 2205 and stainless steel 316L. The material is available in the form of sheets of 6 mm thickness. Its chemical compositions are given in Table I. The base metals are machined to the dimension of 150 mm×100 mm×6 mm, a single - V groove is prepared with an angle of 60°. The surface of the plates was grind to remove the dust and other foreign particles. In order to obtain a strong bonded joint the properties of the base metal and the welding wire must comply with each other. The schematic of welded joint is shown in Fig. 1.

Table-I : CHEMICAL COMPOSITION OF BASE METALS AND FILLER WIRE, (wt. %)

Elements	C	Mn	Cr	Mo	Ni	N
DSS 2205	0.016	0.82	22.48	3.12	5.46	0.16
SS316L	0.03	2	16	3	12	0.1
ER 309LMO	0.03	1.4	23	3	12	0.13

Butt welds were made on plates using GMAW welding processes. GMAW welding establishes an electrical arc between a continuously fed electrode and the weld pool; this is protected by a gas administered externally. The heat generated by the arc melts the base metal surface as well as the electrode tip. The molten electrode is transferred to the workpiece through the electric arc and serves as the filler metal (weld bead).

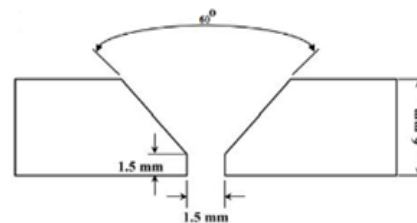


Fig. 1. The type of and size of welding joint

The type of material of welding wire depends upon the material that is required to be welded. The joints are prepared by GMA welding process with ER309LMO welding wire of 0.8 mm diameter was used for optimization. Argon was used as a shielding gas. Three different passes of GMAW were performed. The chemical composition of ER309LMO welding wire is shown in Table I. The significant welding input parameters that can affect the output response were identified and their range of operation was selected as shown in Table II. The welding carried out in flat position with electrode positive. Weld backing is provided by argon gas.



Fig. 2. Experimental Setup

In this work, thyristorised power source of L&T make 'ZUPER ARC 400 T' was used to join 6mm flat plates of DSS 2205 and SS 316L due to their ability to quick arc start, stick out and crater control, Fresh tip Treatment Technology (FTT) to eliminates globule formation at the wire tip during weld stop and others advantage. The effect of the process parameters, viz., voltage, welding current and gas flow rate and focusing position on the weld joint yield tensile strength, ultimate tensile strength, impact strength and weld metal hardness has been investigated.

#### B. Design of Experiments

The methodology of Taguchi for three factors at three levels is used for the implementation of the design of experiments. Taguchi's L9 orthogonal array is used to define the 9 trial conditions. Only the main effects are of interest and factor interactions are not studied. The process parameters and levels are listed in Table II.

TABLE-II : LEVELS OF PROCESS INPUT PARAMETERS

Process Parameter	Level 1	Level 2	Level 3
Voltage (V)	16	18	20
Current (A)	50	70	90
Gas flow rate (l/min)	12	14	16

A series of Vickers hardness test were carried out on welded joints at room temperature to evaluate the hardness values of welded joints. The specimen preparation and the magnitude of test force selection were according to the ASTM: E384 -10. The force of 30 kgf is selected and the test surface is polished to mirror like finish by using emery papers up to grade 1500. The Vickers hardness test were conducted on FIE made Vickers hardness testing machine of model number 'VM-50'.

Table-III : EXPERIMENTAL LAYOUT USING AN L9 ORTHOGONAL ARRAY

Run No.	Welding Voltage (V)	Welding Current (A)	Gas flow rate (l/min)
1	16	50	12
2	16	70	14
3	16	90	16
4	18	50	14
5	18	70	16
6	18	90	12
7	20	50	16
8	20	70	12
9	20	90	14

In order to evaluate the Charpy impact toughness values of welded joints, series of Charpy V-notch test were carried out on welded joints at room temperature. The specimens for Charpy test were taken as perpendicular to weld direction according to the ASTM: E23. Notches were prepared exactly at the midpoint of the weld. The Charpy V-notch tests were conducted on FIE made Impact testing machine of model number 'IT-30'. The tensile tests were conducted for evaluating the yield tensile strength and ultimate tensile strength values of welded joints. The specimens for tensile test were taken according to the ASTM: E8. The tensile tests was tested on FIE make universal testing machine of model number 'UTE-40'. For each of the 9 trials or welding process designs, the response tests are replicated trice and the average response values are used for the analysis. Table IV shows the experimental layout and corresponding average test results.

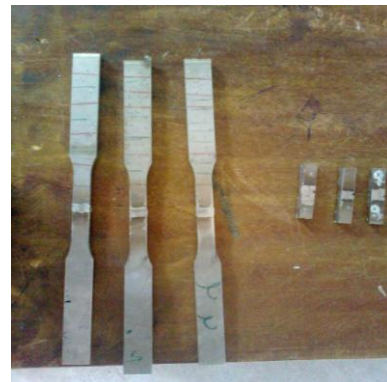


Fig. 3. Tensile and Impact Testing Specimens

TABLE-IV : EXPERIMENTAL RESULTS

Exp. No	Weld metal Hardness , VHN	Yield strength , MPa	Ultimate strength, MPa	Impact strength , J/m2, *10^6
1	238.584646	422.875	460	1.11

2	227.917190	442.86	494.2857	1.78
3	206.488690	371.43	497.143	2.016
4	213.213270	428.57	520	1.5
5	241.574300	417.143	500	2.689
6	230.401030	420	471.42857	2.667
7	217.235000	377.14	497.14	2.437
8	236.620300	422.875	474.286	2.0317
9	251.253270	425.714	514.286	1

5	0.783781	0.639969	0.666667	1.000000
6	0.534180	0.679966	0.190476	0.986975
7	0.240063	0.079938	0.619000	0.850799
8	0.673113	0.719964	0.238100	0.610835
9	1.000000	0.759961	0.904767	0.000000



Fig. 4. Broken Tensile Test Samples



Fig. 5. Broken Impact Test Samples

The determination of which formula to be employed for data normalization is based on the characteristics of a data sequences. Here the expectancy is the higher-the-better, because the objective is to get maximum yield strength, ultimate strength, impact strength of the weld joint and maximum weldmetal hardness. Higher-the-better be expressed by

$$X_{ij} = \frac{Y_{ij} - \min_i Y_{ij}}{\max_i Y_{ij} - \min_i Y_{ij}}$$

Where  $Y_{ij}$  is the  $i^{th}$  performance characteristic in the  $j^{th}$  experiment.  $\max_i Y_{ij}$  and  $\min_i Y_{ij}$  are the maximum and minimum values of  $i^{th}$  performance characteristic for alternate  $j$ , respectively.[18]

Grey Relational Co-efficient (GRC) Calculation: The Grey relational co-efficient is calculated to represent the relationship between the desired and actual data.[18] Grey relational co-efficient (GRC) is

$$\xi_{ij} = \frac{0.5}{|1 - X_{ij}| + 0.5}$$

### III. OPTIMIZATION OF GMAW PROCESS PARAMETERS

#### A. Grey Relational Analysis (GRA)

There are 3 main steps in Grey Relational Analysis. These steps are data pre-processing, grey relational coefficient and Grey relational grade.

1) Data Pre-Processing: Data pre-processing is usually required when the range or unit in one data sequence is different from others or the sequence scatter range is too large [18]. Then implement the data normalization.

TABLE-V : EVALUATED NORMALIZED VALUES

Experiment No.	Hardness	Yield Strength	Ultimate Strength	Impact Strength
1	0.716994	0.719964	0.000000	0.065127
2	0.478693	1.000000	0.571428	0.462700
3	0.000000	0.000000	0.619050	0.601539
4	0.150221	0.799944	1.000000	0.296033

TABLE VI : EVALUATED GREY RELATIONAL CO-EFFICIENT VALUES

Experiment No.	Hardness	Yield Strength	Ultimate Strength	Impact Strength
1	0.638565	0.640996	0.333333	0.34846
2	0.489569	1.000000	0.53846	0.48202
3	0.333333	0.333333	0.56757	0.55651
4	0.370431	0.714229	1.00000	0.41529
5	0.698110	0.581375	0.60000	1.00000
6	0.517695	0.609731	0.38182	0.97461
7	0.396845	0.352097	0.56754	0.77018
8	0.604677	0.640996	0.39623	0.56233
9	1.000000	0.675640	0.84001	0.33333

2) Grey Relational Grade Determination: The grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance characteristics. The overall evaluation of the multiple

performance characteristics is based on the grey relational grade.

$$\gamma_j = \frac{1}{m} \sum_{i=1}^m \xi_{ij}$$

Where  $\gamma_j$  is the grey relational grade for the  $j^{\text{th}}$  experiment and  $m$  is the number of performance characteristics. According to grey relational theory Higher the grey relational grade better is the product quality. So among the nine experiments fifth one is the better, secondly better is ninth one. [18]

TABLE-VII : EVALUATED GREY RELATIONAL GRADE VALUES

Experiment No.	Grey Relational Grade	Rank
1	0.490339	8
2	0.627513	3
3	0.447686	9
4	0.624988	4
5	0.719871	1
6	0.620964	5
7	0.521664	7
8	0.551057	6
9	0.712245	2

Based on the grey relational grade, the factor effect can be estimate and the optimal level for each controllable factor can also be determined. The mean of the grey relational grade for each level of the parameter is summarized and shown in Table VIII.

TABLE VIII : RESPONSE TABLE FOR THE GREY RELATIONAL GRADE

Level Parameter	Grey Relational Grade				Rank
	1	2	3	Max-Mini	
Voltage	0.522	0.655*	0.595	0.133	1
Current	0.546	0.633*	0.594	0.087	3
Gas flow rate	0.554	0.655*	0.563	0.101	2
Total Mean Value of the Grey Relational Grade = 0.590703					
* Optimum Levels, i.e. 18V, 70A, 14l/min					

The larger the grey relational grade, the better is the multiple performance characteristics. However, the relative importance among the parameters for the multiple performance characteristics will still need to be known, so that the optimal combinations of the process parameter levels can be determined more accurately. Higher the grey

relational grade better is the product quality. So as to obtain optimum level, select the level having higher the grey relational grade for each parameter.

Total Mean Value of the Grey Relational Grade is obtained by taking average of the entire nine mean grey relational grades in the table VII or the average of nine grey relational grades in the table VIII. For voltage, higher value of Grey Relational grade corresponding to level 2 in n the table VIII. So optimum value of voltage is 18V. In the case of current higher value of Grey Relational grade corresponding to level 2. So optimum value of current is 70A. Similarly gas flow rate is 14 l/min. The optimum level of welding process parameters are,

Voltage : 18V

Current : 70A

Gas Flow Rate : 14 l/min.

## IV. RESULTS AND DISCUSSION

### A. Analysis of Variance (ANOVA)

The purpose of the analysis of variance is to investigate which welding parameters significantly affect the performance characteristic. The total sum of the squared deviations  $SS_T$  from the total mean of the grey relational grade  $\gamma_m$  can be calculated as:

$$SS_T = \sum_{j=1}^p (\gamma_j - \gamma_m)^2$$

Where  $p$  is the number of experiments in the orthogonal array and  $\gamma_j$  is the mean grey relational grade for the  $j^{\text{th}}$  experiment. The percentage contribution of each of the welding parameter in the total sum of the squared deviations  $SS_T$  can be used to evaluate the importance of the welding parameter change on the performance characteristic [17]. In addition, the Fisher's F- test can also be used to determine which machining parameters have a significant effect on the performance characteristic. Table IX shows the results of ANOVA analysis.

Table- IX : RESULTS OF THE ANALYSIS OF VARIANCE

Source	DF	SS	MS	F	%C
Voltage	2	0.00893	0.00447	4.5657	47.0835
Current	2	0.00381	0.00191	1.9484	20.0922
Gas flow rate	2	0.00623	0.00311	3.1830	32.8242
Error	54	0.05280	0.00098		
Total	60	0.071768		9.6971	100

Results of analysis of variance indicate that Voltage is the most significant welding parameter followed by Gas flow

rate and current respectively affecting the multiple performance characteristics.

### B. Experimental Verification

The optimized values of GMAW input parameters in the welding between DSS 2205 and SS 316 are 18V, 70A, and 14l/min. Once these parameters are obtained, welding is conducted on these parameters. The result of the experiment as follows,

TABLE- X : RESULTS OF CONFIRMATION EXPERIMENT

Yield strength , Mpa	474.2857
Ultimate strength, Mpa	508.857
Impact strength ,J/m <sup>2</sup>	5.142857*10 <sup>6</sup>
Weld metal hard metal Hardness, VHN	222.48
%Elongation	31.67

### C. Regression Analysis

The voltage, current and gas flow rate were considered in the development of mathematical models for ultimate strength, yield strength and impact strength of weld joint and weldmetal hardness. The correlation between factors and responses on the welding between DSS 2205 and SS 316L were obtained by multiple linear regressions. SPSS software package was used to derive the mathematical models.

- Impact strength =  $856044.444 + 46891.667V + 5300C + 111108.33G$
- Yield Strength =  $554.827 - 0.953V - 0.095C - 8.336G$
- Ultimate Strength =  $333.973 + 2.857V + 0.48C + 7.381G$
- Hardness =  $216.956 + 2.677V + 0.159C - 3.359G$
- Where; V is the voltage, C is the current, and G is the gas flow rate.

### D. Microstructure of GMA welded joints

The microstructure of the used 2205 duplex stainless steel base metal is shown in Fig. 6(a). The darker areas represent the  $\alpha$ -ferrite phase, while the lighter areas represent the  $\gamma$ -austenite phase in the micrographs [13]. It was noticed that this microstructure is duplex with approximately equal volumes of both ferrite and austenite phases. Fig. 6(b).shows the microstructure of base metal SS316L and the lighter areas represent the  $\gamma$ -austenite phase in the micrographs [13]. Fig.6 (d).shows the microstructure of weld metal. GMAW is carried out in

three number of passes and also HAZ of SS316L heated above 1050° repeatedly. Fig. 6(c).shows the microstructure of HAZ of base metal SS316L. It is clearly noticed that large amount of ferrite, which is due to the transformation of austenite to ferrite phase.

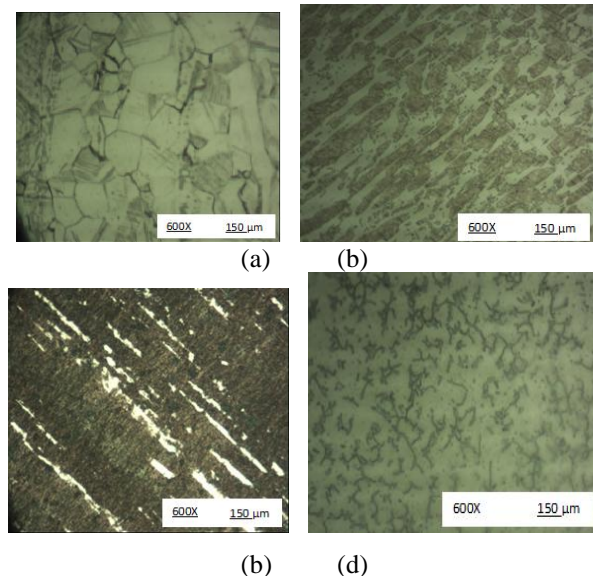


Fig. 6. Microstructure of (a)SS316L, (b) DSS2205, (c)SS316L HAZ, (d)weldmetal

## V. CONCLUSION

In this study, experimentation has been done to simulate the GMA welding between DSS 2205 and 316L. Yield strength, ultimate strength, weld metal hardness and impact strength of joints were investigated considering three process parameters: Voltage (V), Current (I) and Gas flow rate. Then a multi objective Optimization was carried out using multi objective optimization technique grey relational theory is used to set up proper welding process parameters. The optimum process parameter is 18V, 70A and 14l/min gas flow rate. Analysis of variance indicate that Voltage is the most significant welding parameter followed by Gas flow rate and current respectively affecting the multiple performance characteristics.

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## REFERENCES

- [1] Poznansky, C.S. Nalbone, J.D. Crawford, "The corrosion resistance of 25Cr-3.5Mo-6Ni and 25Cr4.5Mo-6Ni cast duplex stainless steels",

- Proc. Conf. DuplexStainless Steels, ASM (1983) 431–444.
- [2] J. Honeycombe, T.G. Gooch, “Intergranular attack in welded stress-corrosion resistant stainless steels”, *Weld. J.* 56 (11) (1977) 339-s–353-s.
- [3] A-H.I. Mourad, A. Khourshid, T. Sharef, “Gas tungsten arc and laser beam welding processes effects on duplex stainless steel 2205 properties”, *Materials Science and Engineering A* 549 (2012) 105– 113.
- [4] M. Tynell, “Applicability range for a high strength duplex stainless steel in deep sour oil and gas wells”, *Proc. Conf. Duplex Stainless Steels, ASM* (1983) 283292.
- [5] H. Miyuki, T. Kudo, M. Koso, M. Miura, T. Moroishi, “25%Cr containing duplex phase stainless steel for hot sea water applications”, *Proc. Conf. Duplex Stainless Steels, ASM* (1983) 95–112.
- [6] T. Omura, T. Kushida, Y. Komizo, “Nitrogen distribution on rapid solidification in laser welded duplex stainless steels”, *Weld. Int.* 14 (4) (2000) 288–294.
- [7] Luo J, Liu DJ, Zhao GJ, Wang XJ, Ran HQ. “Relationship between microstructure of fusion zone and mechanical properties of 2205 duplex stainless steel joint in double-sided submerged arc welding”. *Rare Metal Materials and Engineering* 2011; 40:369–74.
- [8] Antony PJ, Singh Raman RK, Kumar P, Raman R. “Corrosion of 2205 duplex stainless steel weldment in chloride medium containing sulfate-reducing bacteria”. *Metallurgical and Materials Transactions A* 2008; 39:2689–97.
- [9] Luo J, Liu DJ, Yin DK, Yang JF, Zhang YC, Akiyama T. “Influence of welding power to the microstructure and properties of 304 stainless steel sheet joints in CO2 laser welding”. *Rare Metal Materials and Engineering* 2011; 40:106–10.
- [10] Sathiya P, Aravindan S, Soundararajan R, Noorul Haq A. “Effect of shielding gases on mechanical and metallurgical properties of duplex stainless-steel welds”. *Journal of Materials Science* 2009; 44:114–21.
- [11] Ure~na A, Otero E, Utrilla MV, Munez CJ. “Weldability of a 2205 duplex stainless steel using plasma arc welding”. *Journal of Materials Processing Technology* 2007; 182:624–31.
- [12] Shaogang Wang\*, Qihui Ma, Yan Li. “Characterization of microstructure, mechanical properties and corrosion resistance of dissimilar welded joint between 2205 duplex stainless steel and 16MnR”. *Materials and Design* 32 (2011) 831–837.
- [13] Jianyu Xiong, Mike Yongjun Tan , Maria Forsyth, “The corrosion behaviors of stainless steel weldments in sodium chloride solution observed using a novel electrochemical measurement approach”; *Desalination* 327 (2013) 39–45.
- [14] Platt JA, Guzman A, Zuccari A, Thornburg DW, Rhodes BF, Oshida Y, Moore BK, “Corrosion behavior of 2205 duplex stainless steel” , *Am J Orthod Dentofacial Orthop.* 1997 Jul; 112(1):69-79.
- [15] Shop sheet 104, “Practical Guide Lines for Fabrication of Duplex Stainless Steels”, Second Edition 2009, International Molybdenum Association 07/14.
- [16] Gadakh. V.S, 2012; “Parameteric Optimization of Wire Electrical Discharge Machining using Topsis Method”, *Advances in Production Engineering and Management* 7(3), p.157
- [17] Lohithaksha Maiyar, Dr.R.Ramanujam; “Optimization of Machining Parameters for End Milling of Inconel 718 Super Alloy Using Taguchi Based Grey Relational Analysis” *Procedia Engineering* 64 ( 2013 ) 1276 – 1282.
- [18] Roselina Sallehuddin, Siti Mariyam Hj. Shamsuddin, Siti Zaiton Mohd Hashim; “Grey Relational Analysis And Its Application On Multivariate Time series” .

